Reimagining STEM Education and Training with e-REAL: 3D and Holographic Visualization, Immersive and Interactive Learning for an Effective Flipped Classroom

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***Abstract*—While the 19th and the 20th centuries were, in education, mainly about standardization, the 21st century is about visualization, interaction, customization, gamification and flipped teaching. What today we know about learning from cognitive psychology is that people learn by practicing, with feedback to tell them what they're doing right and wrong and how to get better. For STEM education, that means they need to practice thinking like a scientist in the field. So e-REAL is a cornerstone: developed as workplace learning system in a number of fields (from medical simulation to soft skills development within the continuing education), it's an ideal solution to root a practical – but not simplicistic - approach for STEM education.**

***Index Terms*—e-REAL, Flipped Classroom, Immersive and Interactive Learning, STEM Education and Training.**

I. THE PAST AND THE FUTURE IN TEACHING AND LEARNING STEM: A SAGE ON THE STAGE OR A FLIPPED CLASSROOM?

College lecture classes, in which students are primarily listening and taking notes, have been around for more than 900 years. The traditional pattern of teaching has been to assign students to read textbooks and work on problem sets outside school, while listening to lectures and taking tests in class. If everything the students are supposed to learn in a course is covered in lectures and readings, then the instructors have successfully taught the course, regardless of whether or not anyone learned it!

That is teacher-centered instruction, in which the course instructor is supposed to be in control of everything that happens in the course except how the students react and achieve. In such a scenario, to teach means to show or explain something: unfortunately, many STEM instructors follow such a path that has been practiced for centuries throughout the world. The students mainly sit through the lectures—some occasionally asking or answering questions and most just passively observing [1].

Lately, a handful of science and engineering professors have been experimenting with a more innovative way of teaching science, especially at the introductory level. In such a different approach, to teach means to cause to know something. Teaching and learning are correlative or corresponding processes, as much so as selling and buying. One might as well say he has sold when no one has bought, as to say that he has taught when no one has learned [2]. This is learner-centered teaching. The students are no longer passive recipients and repeaters of information [3], but take much more responsibility for their own learning. The instructor functions not as the sole source of wisdom and knowledge to them but more as a coach or mentor, whose task is to help them acquire the desired knowledge and skills for themselves [4].

By the 20th century, all major industrialized countries offered formal education and training to the population. When the curricula took shape in the 19th and 20th centuries, scientists didn't know very much about how people learn. Even by the 1920s, when schools began to become the large bureaucratic institutions that we know today, there still was no sustained study of how people learn. As a result, the major parts of the educational institutions we have today were designed around commonsense assumptions that had never been tested scientifically [5].

While the 19th and the 20th centuries were, in education, mainly about standardization, the 21st century is about visualization, interaction, customization, "cheapification", gamification and some other relevant trends such as the flipped teaching.

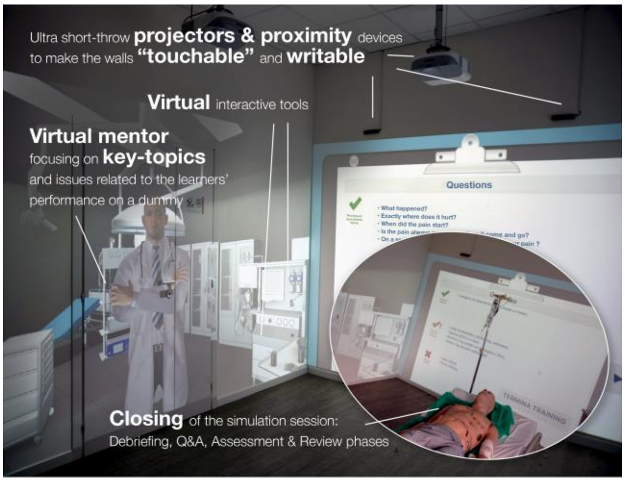

Figure 1. e-REAL lab: Interaction with 2D and 3D images projected by very powerful ultra-short throw projectors--allowing flipped learning both face-to-face and online in a CAVE-like setting easier, more powerful and less expensive.

What today we know about learning from cognitive psychology is that people learn by practicing, with feedback to tell them what they're doing right and wrong and how to get better. That means they need to practice thinking like a scientist in the field. They should do background reading that gives basic information before class and then in class they're working through carefully designed problems that give them practice at a particular sort of scientific thinking, whether it's how physicists think about forces in motion, or how biologists think about cells and how they repair themselves, and so on. This way, they get much more targeted feedback from the instructor, who can realize they're confused about some basic point and can guide them much more directly. In this way, students spend all of their time in class being very actively involved, using their brains strenuously [6].

This active learning approach is designed to have the student working on tasks that simulate an aspect of expert reasoning and problem-solving, while receiving timely and specific feedback from fellow students and the instructor that guides them on how to improve. These elements of authentic practice and feedback are general requirements for developing expertise at all levels and disciplines and are absent in lectures.

Figure 2. e-REAL lab: Working on tasks that simulate an aspect of expert reasoning and problem solving

Figure 3. e-REAL lab: feedback from fellow students and the instructor

Flip teaching is an interesting example: the students first study the topic by themselves, typically using video lessons prepared by the teacher or third parties. In class students apply the knowledge by solving problems and doing practical work. The teacher tutors the students when they become stuck, rather than imparting the initial lesson in person. Complementary techniques include differentiated instruction and project-based learning. Flipped classrooms free class time for hands-on work. Students learn by doing and asking questions. Students can also help each other, a process that benefits both the advanced and less advanced learners [7].

Flipped classroom is an instructional strategy and a type of blended learning that reverses the traditional learning environment by delivering instructional content, often online, outside of the classroom. It moves activities, including those that may have traditionally been considered homework, into the classroom. In a flipped classroom, students watch online lectures, collaborate in online discussions, or carry out research at home and engage in concepts in the classroom with the guidance of a mentor.

The flipped classroom intentionally shifts instruction to a learner-centered model in which class time explores topics in greater depth and creates meaningful learning opportunities, while educational technologies such as online videos are used to deliver content outside of the classroom. In a flipped classroom, content delivery may take a variety of forms. Often, video lessons prepared by the teacher or third parties are used to deliver content, although online collaborative discussions, digital research, and text readings may be used.

Class activities vary but may include: using emerging mathematical technologies, in-depth laboratory experiments, original document analysis, debate or speech presentation, current event discussions, peer reviewing, project-based learning, and skill development or concept practice. Because these types of active learning allow for highly differentiated instruction, more time can be spent in class on higher-order thinking skills such as problem-finding, collaboration, design and problem solving as students tackle difficult problems, work in groups, research, and construct knowledge with the help of their teacher and peers. Students are actively involved in knowledge acquisition and construction as they participate in and evaluate their learning.

Flipped mastery eliminates two other out-of-class routines: daily lesson planning and grading papers. The latter happens in class and in person. Replacing lectures with group and individual activities increases in-class activity. Every student has something to do throughout the class. In some classes, students choose how to demonstrate mastery—testing, writing, speaking, debating and even designing a related game. Learning Management Systems such as Moodle or ILIAS provide ways to manage the testing process. They create a different test for each student from a pool of questions. Advocates claim that its efficiency allows most students to do a year's work in much less time. Advanced students work on independent projects while slower learners get more personalized instruction. Some students might not get through the year's material, but demonstrate but competence on the parts they did complete [8].

II. FROM THE FLIPPED CLASSROOM TO E-REAL

Critics argue that the flipped classroom model has some drawbacks for both students and teachers. A number of criticisms have been discussed. Let’s focus only on the following issue which we will soon better introduce, that could also be relevant for e-REAL, with the solution displayed in the figures. In a nutshell: flipped classrooms based mainly on videos suffer some of the same challenges as traditional classrooms; students may not learn best by listening to a lecture, and watching instructional videos at home is still representative of a more traditional form of teaching. Critics argue that a constructivist approach would be more beneficial, and that is why—as well the way—e-REAL is at the forefront by design.

From a constructivist point of view, knowledge is mainly the product of personal and inter-personal exchange. Knowledge is constructed within the context of a person’s actions, so it is "situated": it develops in dialogic and interpersonal terms, through forms of collaboration and social negotiation. Significant knowledge--and know-how--is the result of the link between abstraction and concrete behaviors, in order to make the intangible more tangible. Knowledge and action can be considered as one: facts, information, descriptions, skills, know-how and competence--acquired through experience, education and training. Knowledge is a multifaceted asset: implicit, explicit, informal, systematic, practical, theoretical, theory-laden, partial, situated, scientific, based on experience and experiments, personal, shared, repeatable, adaptable, compliant with socio-professional and epistemic principles, observable, metaphorical, linguistically mediated. Knowledge is a fluid notion and a dynamic process, involving complex cognitive and emotional elements for both its acquisition and use: perception, communication, association and reasoning. In the end, knowledge derives from minds at work. Knowledge is socially constructed, so learning is a process of social action and engagement involving ways of thinking, doing and communicating [9].

e-REAL–which stands for Enhanced Reality Lab--is a powerful tool based on Enhanced Reality technologies, designed for lifelong learning, capacity building, educational events, interactive edutainment, and immersive experiences.

Figure 4. e-REAL lab: interactive hologram

e-REAL integrates things, tools and objects from the real world within a multisensory scenario, based on short case-studies developed by visual storytelling techniques. Learners are completely immersed in a 3D or holographic scenario where they can interact with the contents by natural gestures--without the constraint of wearing glasses, gloves or headsets.

Figure 5. e-REAL lab: real smoke in a virtual scenario

As an educational setting, e-REAL is a highly interactive and face-to-face lab that promotes proactive data and information research: everything is available, but learners have to actively look for it. It also allows online learning and knowledge sharing with remote teams, as well as interactive and cooperative e-learning.

It's quite a "futuristic" educational environment: in the below images, representative classrooms are shown.

Figure 6. e-REAL lab: Physics

Figure 7. e-REAL lab: Chemistry

Figure 8. e-REAL lab: Biology

Figure 9. e-REAL lab: Disaster Management

Figure 10. e-REAL lab: Mathematics

Figure 11. e-REAL lab: IT Engineering

Figure 12. e-REAL lab: Geology

In development since 2011, in order to evolve from the old CAVE environments (too rigid, difficult to be managed and expensive) to an easy, user-centered and cost-effective solution, e-REAL takes users in a full interactive and immersive ecosystem [10]. It is easier to be managed, more powerful and 10 times less expensive compared with a traditional CAVE--mainly because e-

REAL is based on ultra-short throw projections instead of rear-projected walls.

According to the first tests made by our team between 2013-2016, discussed during the latest three ICELW conferences on e-learning in the workplace [11], the learner performance gain is 43% (in terms of faster and easier learning, as well as in better exam/assessment results) and 88% of learners have more engagement and fun going through the program. Moreover, due to the 10 times decreased cost of the e-REAL immersive room compared to the CAVE-like environments, the added value that e-REAL already brings to the field of education is pretty evident.

Students are completely immersed in a 3D scenario where they can interact by natural gestures and experience the world from different perspectives at the same time (systems and complex thinking). It further includes live and real time interaction with peers, trainers, tutors, facilitators or mentors. And thus, this adds a very important social component that enhances learning outputs, as well as metacognitive processes and skills.

The e-REAL model is often interdisciplinary in its approach, and a number of times encourages projects that involve the community at large. The combination of allowing students to choose their challenge and linking these challenges to community interaction increases students' investment in a productive outcome. It encourages students to take advantage of the technology they use in their daily lives to solve real-world problems. Its essence is collaborative and requires students to work with other students, their teachers and experts in their communities around the world to develop a deeper understanding of the subjects they are studying. To assume and solve the challenges, to act, to share their experience, is an important part of its didactic essence and all take advantage of the ubiquitous possibilities generated by the e-REAL ecosystem.

III. REIMAGINING STEM EDUCATION AND TRAINING WITH E-REAL

Effective STEM teaching can propel a country to the forefront of an innovation-based global economy. e-REAL is an ideal mean to propel STEM education and training because it is designed around five pillars: systems thinking, model-based reasoning, quantitative reasoning, equity, epistemic and ethical outcomes; and STEM communication and outreach. These pillars are substantial elements of an effective STEM curriculum, because they are critical for the successful execution of real-world activities STEM related [12].

Behind those pillar elements there is an overall vision and an epistemology that we are about to summarize here. Humans are physical, biological, psychological, cultural, social, historical beings. This complex unity of human nature has been so thoroughly disintegrated by education and divided into disciplines. Restoring this complex unity means moving away from an influent paradigm—the mind-body dualism—formulated by Descartes and imposed by developments in European history since the 17th century. The Cartesian paradigm disconnects subject and object, each in its own sphere: philosophy, epistemology and reflective research here, science and objective research there. It is indeed a paradigm that unconsciously irrigates and controls our conscious thought, making it also super-conscious [13]. This paradigm determines a double vision of the world, in fact a doubling of the world and of educational systems (usually divided in the science or humanities curricula). One is a world of objects that can be observed, experimented, manipulated; the other is a world of subjects that raise problems of existence, communication, conscience, destiny.

A paradigm institutes primordial relations that form axioms, determine concepts, command discourse and/or theories. It organizes their organization and generates their generation or regeneration. A paradigm may elucidate and blind, reveal and obscure. There, deeply ensconced inside the paradigm, lies a crucial factor in the game of truth and error. In short, a paradigm determines the sovereign concepts and prescribes the logical relation of disconnection. Disobedience to this disconnection is necessarily clandestine, marginal, deviant.

Even if the Cartesian body-mind dualism historically lost its attraction very early on, the notion that mental life is “internal” and separate from behavior, which is “external,” survived much longer and can still be found today in many psychological, pedagogical and andragogical approaches. This situation results in a uniting and managing of impoverished, simplified models and conceptual human action that cannot be used in the dense and polysemic dynamics of our daily lives. Perhaps it is no coincidence that we still often bring into account learning environments that, doing a little “archaeology of knowledge”, we could trace back to the model of the Panopticon [14]--or rather prison, hospital, factory or school--that shows everything thanks to the spoke shape of the building: an environment where ideally a single observer may watch everything all the time, adding to the perceptions of the inmates (or patients, workers, students), a sort of omniscience and generalized control by the guardian. This occurs in an environment—the Panopticon—where learning is conceived as a passing of information from the lecturer to the student, following a communicative process that tends to be one-way (top-down) and within which the “retroactions,” the feed-back (bottom-up), take on the role of interrogations [15].

Panoptism is a philosophy and a vision-guide, the discipline as a base assumption of the psycho-pedagogical procedures; taylorism (and its many "neo" variations) as an organizational model. But the Panopticon is not exactly the type of benchmark to look towards for inspiration, unless you wish to "re-edit" Charlie Chaplin in "Modern Times," or any other form of neo-taylorism.

We live in a 4.0 world, where cooperative learning interaction, that is not too structured and is a little centralized, helps a lot in terms of flexibility and enrichment of the cognitive maps. Instead of being inspired by the Panopticon, we should consider both educational environments as well as the human mind to be complex systems. In particular, the human mind works as a meeting point for a wide range of structuring influences whose nature may only be represented on a much larger canvas than that provided by the study of individual organisms. People are “agents” who must produce their own constructive interpretations and the expressive acts starting from the contexts in which they are rooted and within which we all live, move and realize our being.

Students are in need of new ways of thinking that are able to process peculiarities, individualities, oddities, discontinuities, contrasts and singularities. People have many different and discrete facets of cognition, so they have different cognitive strengths and contrasting cognitive styles. A radically different view of the mind and intelligence that yields a very different vision of education is needed today, because a revolution is under way due to a number of big changes that are emerging at the same time: high-speed mobile networks, cheap tablet devices, the ability to process huge amounts of data cheaply, sophisticated online gaming, adaptive-learning software, "stellar" contents available, often for free. The job of the STEM teachers and trainers, at every educational and training stage, is moving from orator to coach and learning facilitator [16].

As both educational approaches and information technologies evolve, so do the possibilities for more immersive learning and teaching techniques. e-REAL is using cutting edge technologies to create both a virtual and a physical environment in a classroom, which immerses students in real life situations (designed by visual storytelling techniques), with possibilities to interact simultaneously with peers, tutors and learning facilitators, thematic experts and colleagues (both on-site and remotely), as well as consulting literature, records and other written information--that are available as multimedia content.

In the e-REAL scenario learners practice handling realistic situations, rather than learning facts or techniques out of context. Students need to practice thinking—and behaving—like a scientist in the field. In the end, they enter the complexity of real life with a smarter approach. That is why e-REAL is a cornerstone: developed as workplace learning system in a number of fields (from medical simulation to soft skills development within the continuing education), it's an ideal solution to root a practical – but not simplicistic - approach for STEM education.

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